Micromagnetic and analytic study of small zigzag sensors

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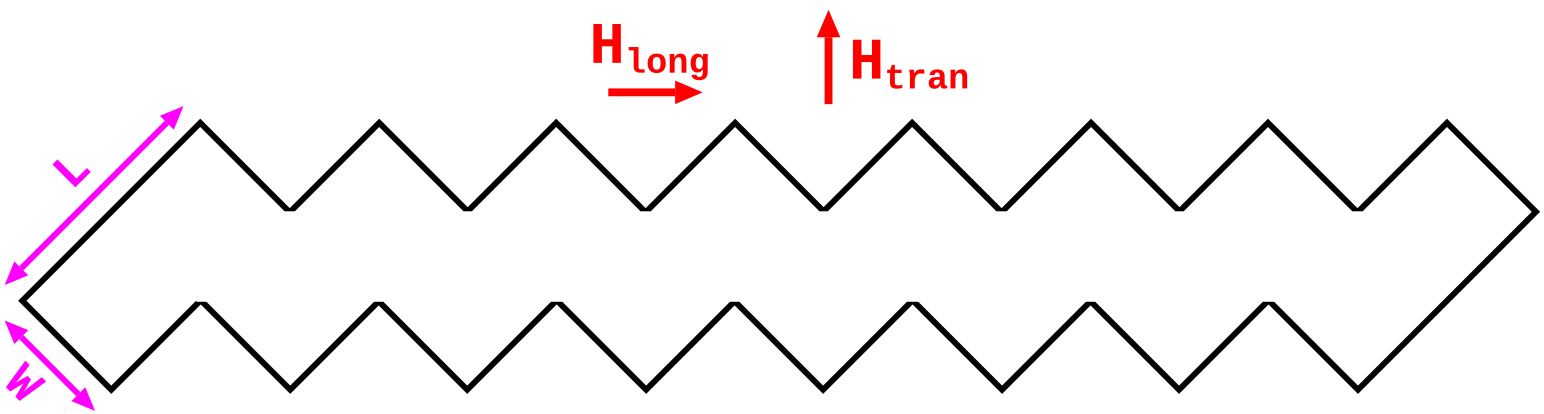
Introduction

Zigzag shaped elements are studied as prototypes for low field magnetic sensors [2]. The elements are composed of rectangular blocks of size L x L/2 x 20 nm, where L varies from 500 nm to 50 nm. The shape anisotropy of the blocks causes the magnetization to scissor back and forth between blocks with tilt angle θ, changing the resistance of the strip through the AMR effect. The sensitivity of the resistance to fields applied both along and transverse to the strip is studied, as a function of L.

Geometry

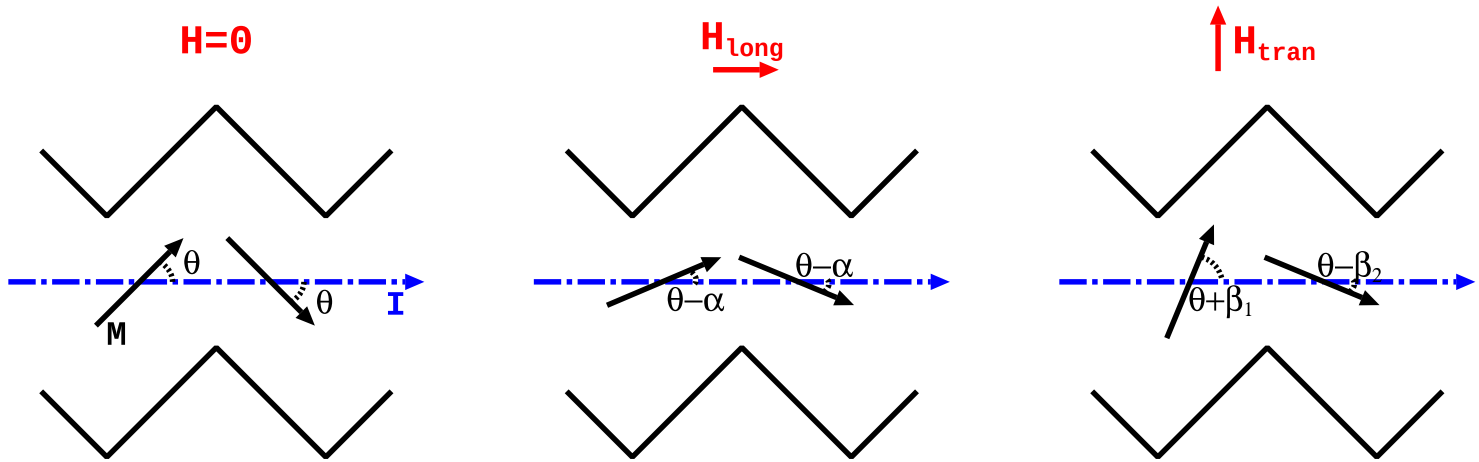


50 nm < L < 500 nm
W = 0.5 L
Thickness = 20 nm

Py material parameters:

A = 13 pJ/m
K = 0 J/m^3
M_s = 800 kA/m

Reaction to applied field



Resistance $R(\theta) = R_0\,(1+\lambda\cos^2\theta)$

Following computations take λ=3%.

$R = R_0\,(1+\lambda\cos^2(\theta-\alpha))$

$\approx R(\theta) + 2R_0\,\lambda\cos\theta\sin\theta\;\alpha$

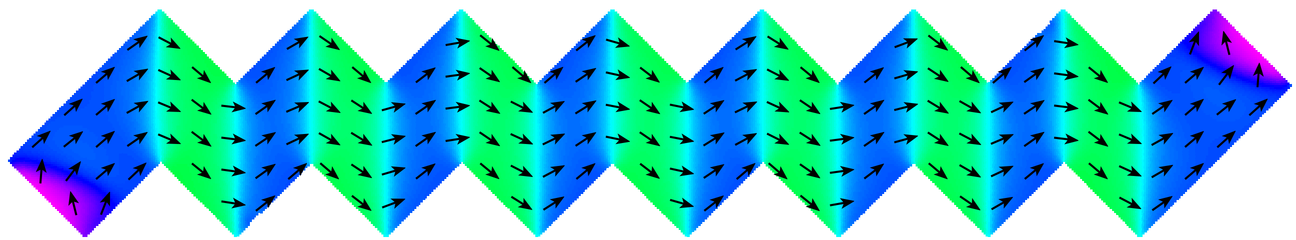
$R \approx R(\theta) + R_0\,\lambda\cos\theta\sin\theta\,(\beta_2-\beta_1)$

$+\, R_0\,\lambda\,(1\text{-}2\cos^2\theta)\,(\beta_1^2+\beta_2^2)/2$

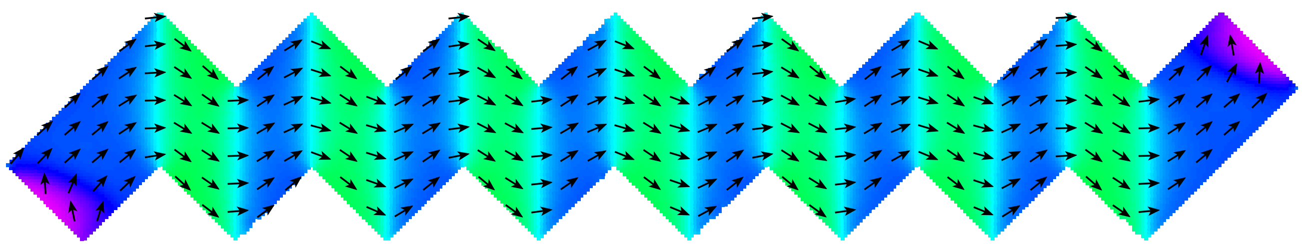
H_{tran} small $\Rightarrow \beta_1\approx\beta_2 \Rightarrow$ good rejection

Also, $\theta=\pi/4 \Rightarrow (1\text{-}2\cos^2\theta) = 0$

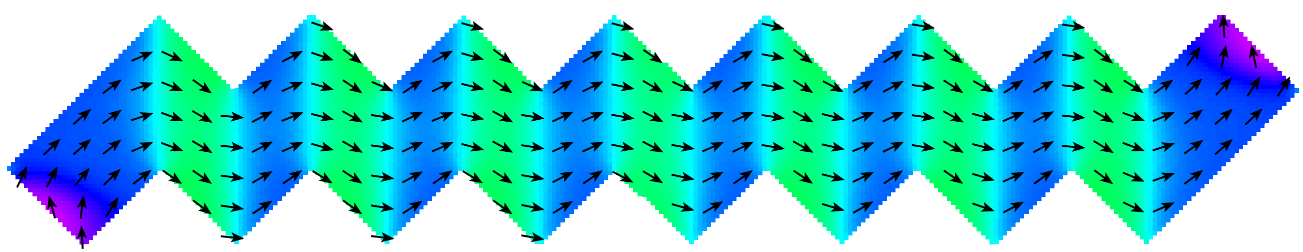
Remanent magnetization



L=500 nm

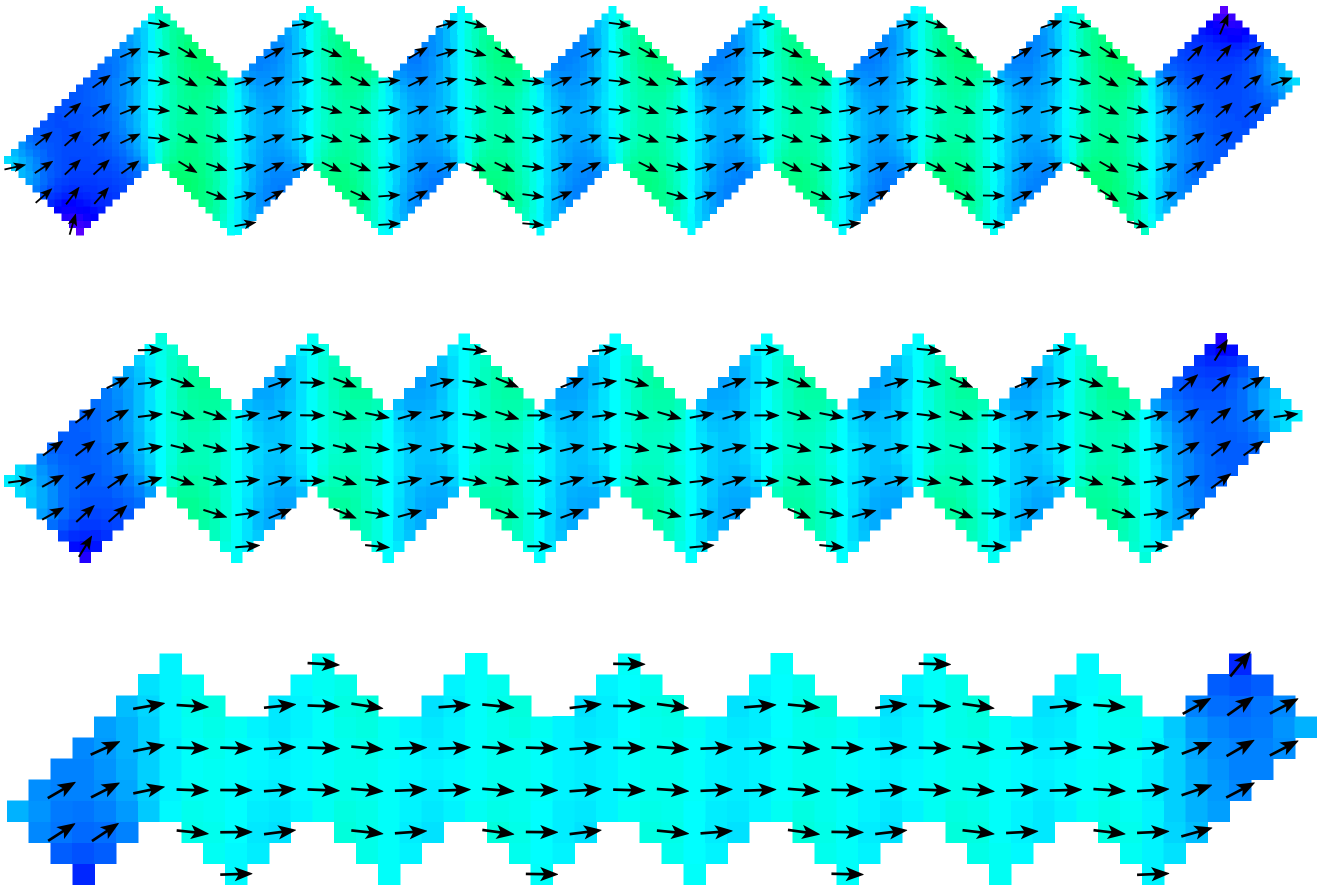


L=350 nm

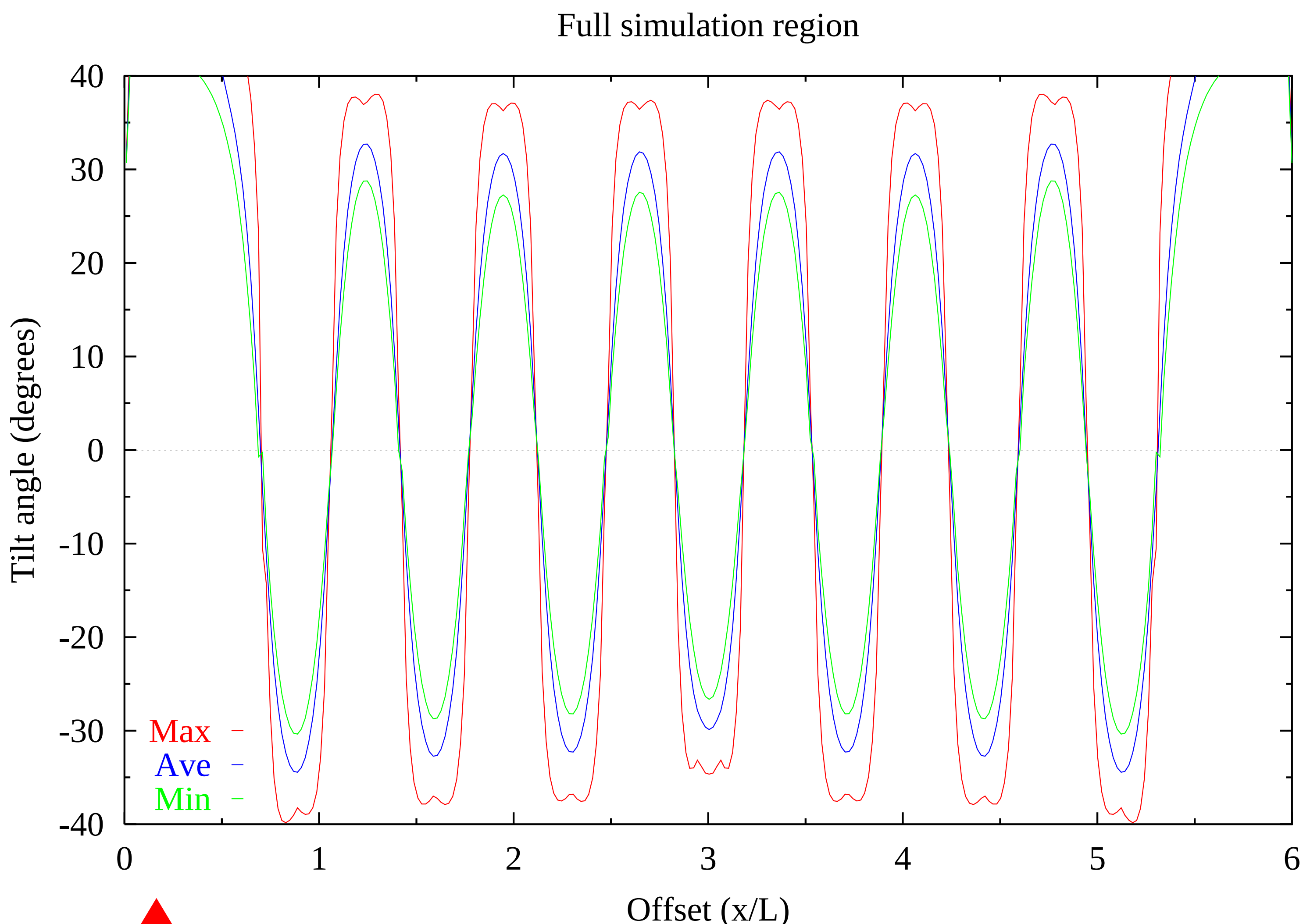


L=250 nm

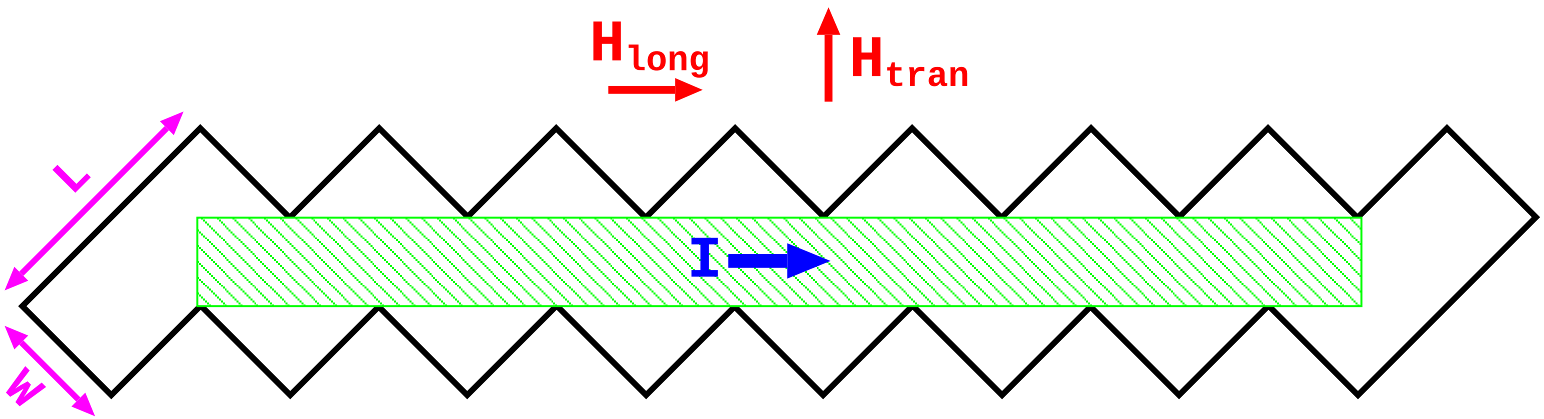
Remanent magnetization



Tilt angle, H=0, L=250 nm

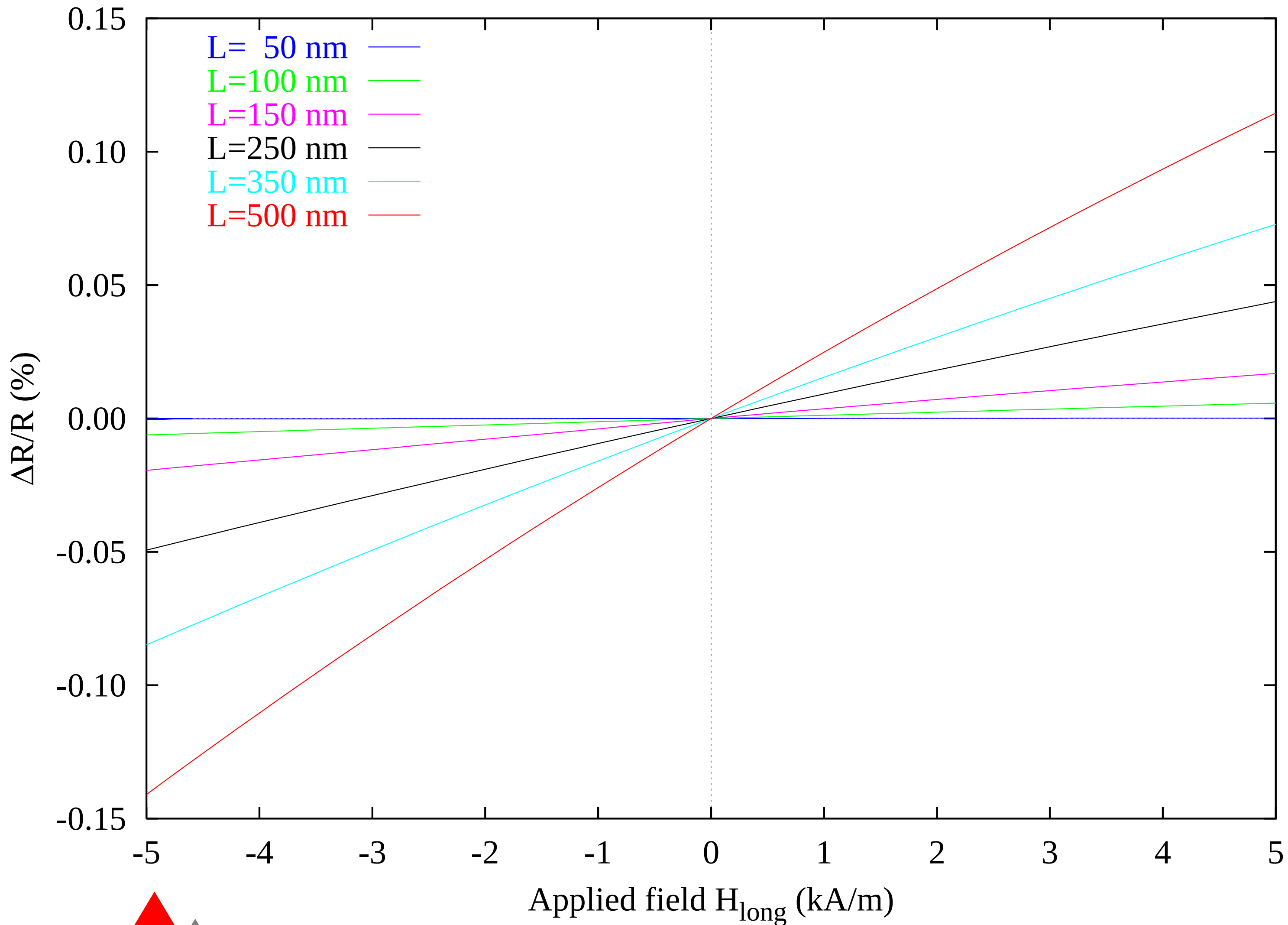


Compute box

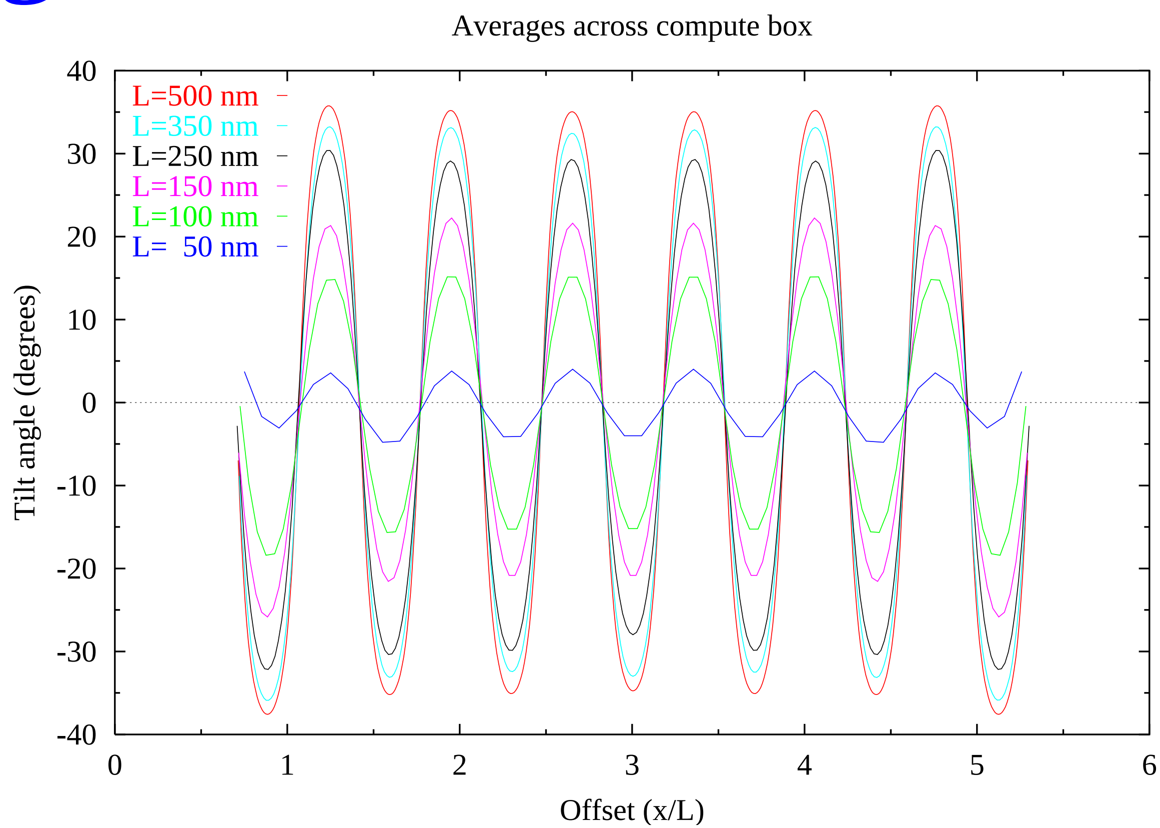


Resistance model assumes current flows parallel to strip axis, restricted to indicated region.

Transfer curves

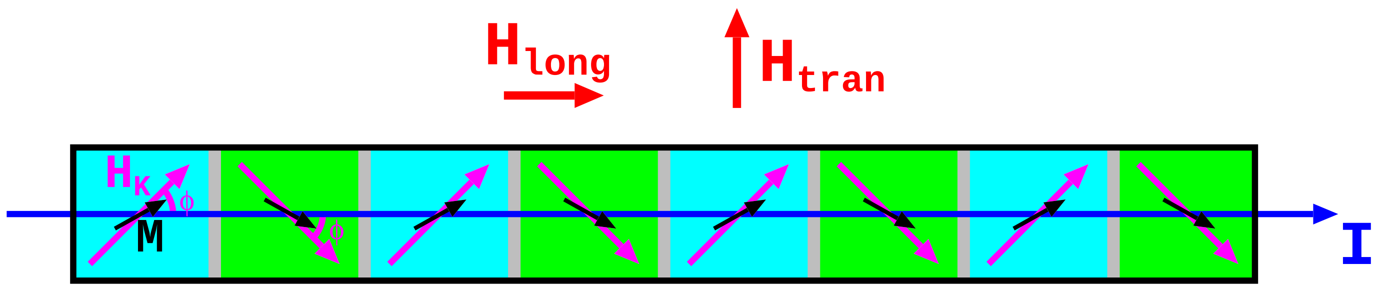


Tilt angle, H=0



Exchange coupling between blocks reduces tilt angle and inhibits sensitivity, especially for small blocks.

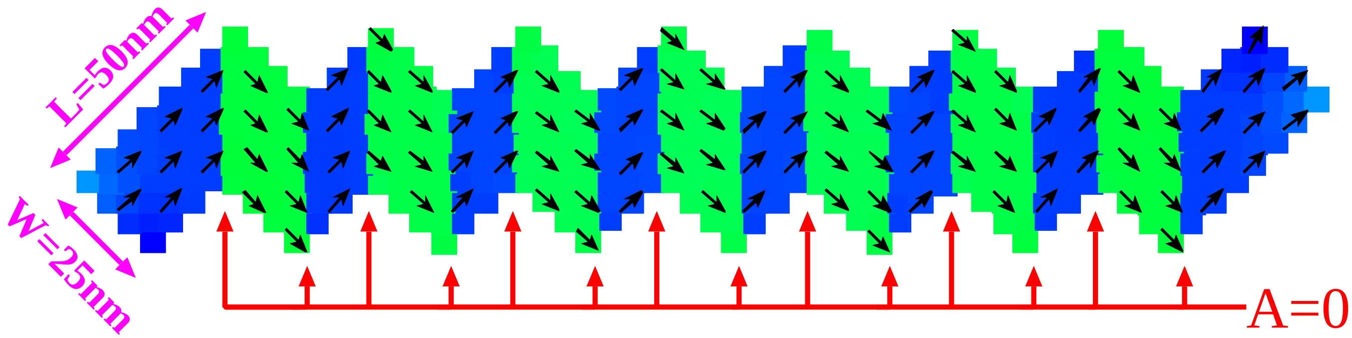
Chain of spins model



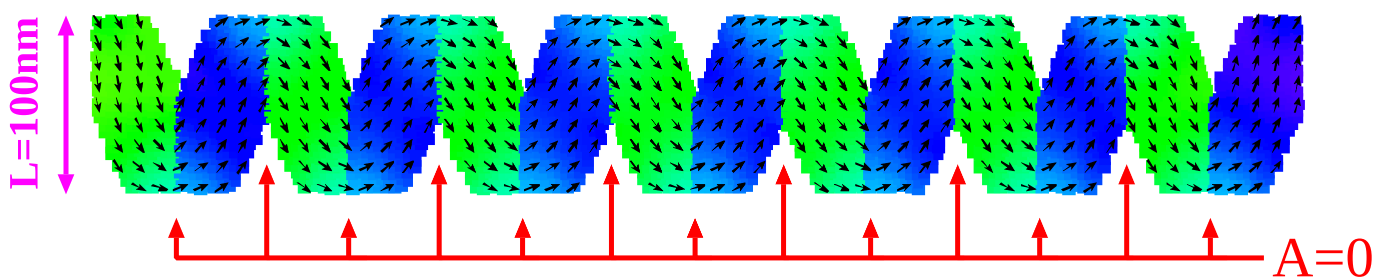
- Each block: single spin, effective anisotropy field $\mathbf{H}_K$; no exchange, no demag.
- Parameters: $\mathbf{H}_K$ direction ϕ and magnitude.
- $\partial R/\partial H_{\mathrm{long}}|_{H_{\mathrm{long}}=0} = 2R_0\lambda\cos\phi\sin^2\phi/H_K$.
- Max sensitivity: small H_K, $\phi = \arctan\sqrt{2} \doteq 54.7^\circ$

Small device modifications

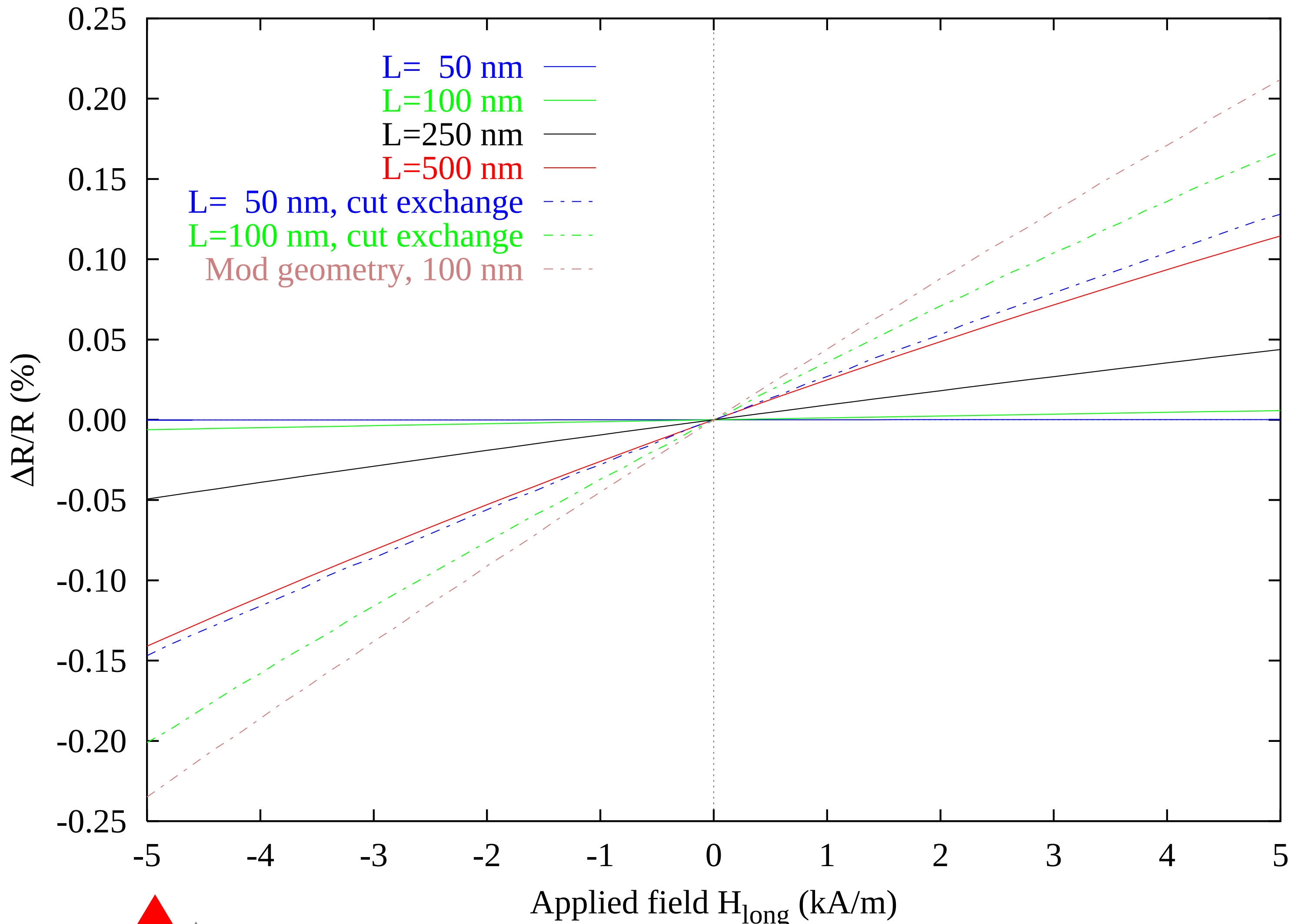
1. Break exchange coupling between blocks:



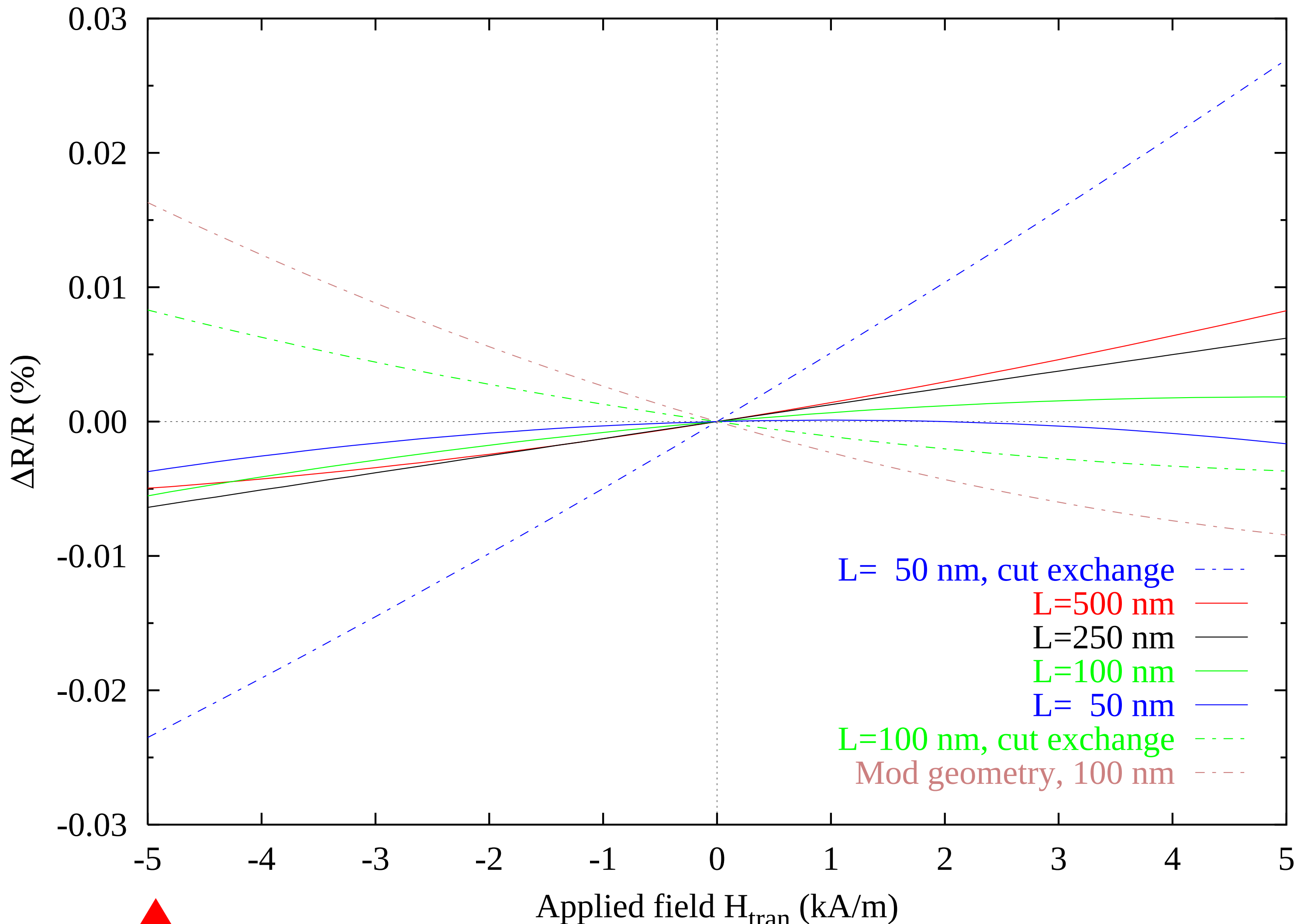
2. Modify block geometry to increase remanent tilt angle to $\approx 55^\circ$:



Transfer curve redux



H_{tran} *sensitivity*



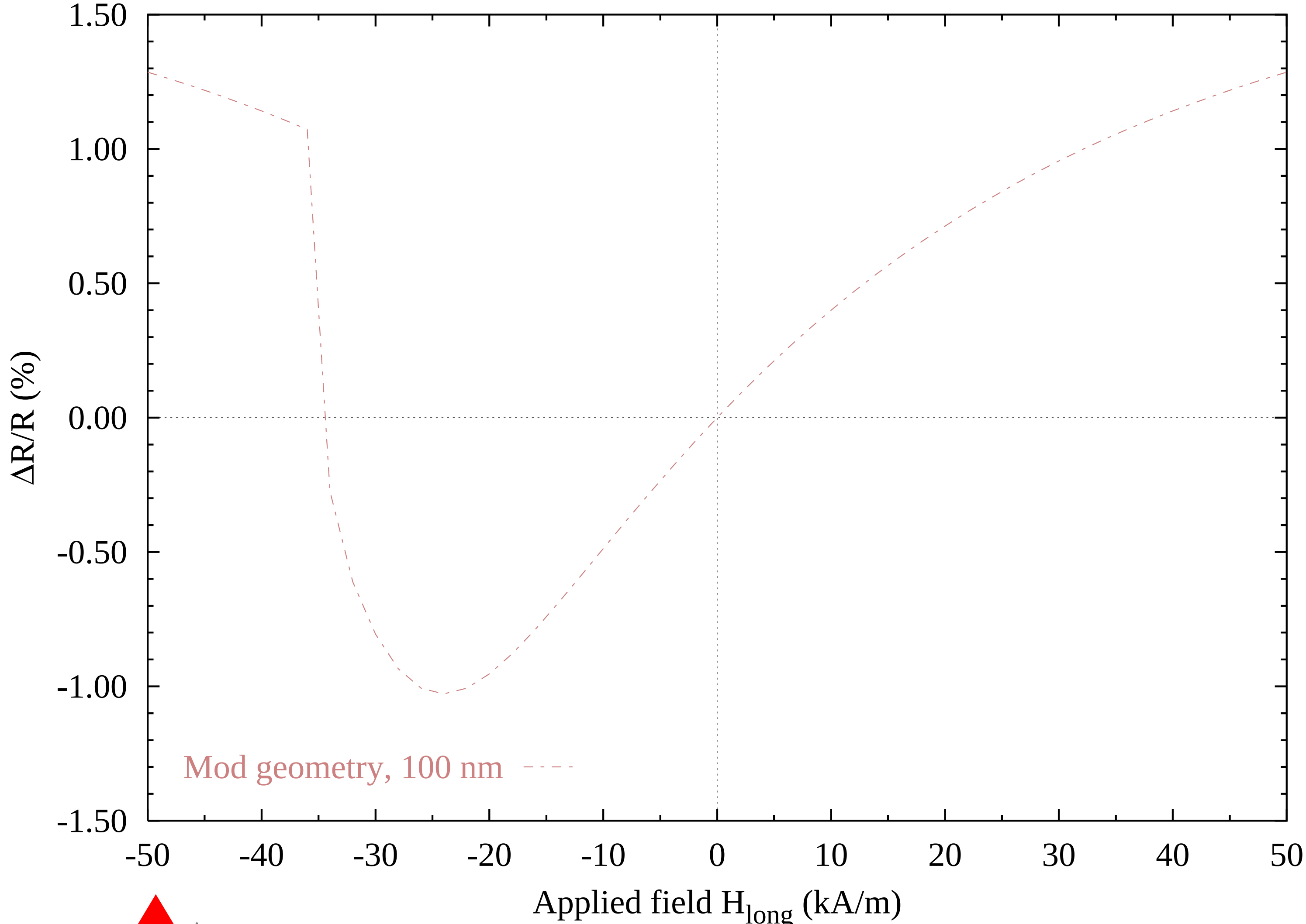
Summary

- Zigzag geometry yields effective low-field directional sensors.
- As block dimensions shrink, exchange coupling between blocks reduces sensitivity.
- Size effect can be largely but not completely removed by breaking exchange coupling between blocks.
- Minor modifications to part geometry can improve sensitivity.

References

1. This work is part of the NIST Competence Project, "Nano-scale Engineered Sensors for Ultra-low Magnetic Field Metrology."
2. "Zigzag shaped magnetic sensors," F.C.S. da Silva, W.C. Uhlig, A.B. Kos, J. Aumentado, M.J. Donahue, J. Unguris, and D.P. Pappas, submitted to Appl. Phys. Lett.

Extended transfer curve



Thermal, L=125 nm